SMEs and the Sustainability Challenge

Digital Shadow Enabling Smart Decision Making

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Abstract
In this chapter, we discuss the challenges SMEs are facing when working with sustainability. Two main issues are addressed. Firstly, making proper sustainability decisions requires expertise rarely possessed by SMEs. As presented in the chapter, there are many assessment tools available, but these are difficult to use for non-experts and often based on inconsequent value choices. Therefore, it is recommended that companies instead partly focus on knowing the physical flows of material and energy related to company activities, and partly seek understanding of how these interact with the surrounding systems. Secondly, sustainability is often assessed in the design phase only, often based on incomplete and overall global sustainability evaluations. This is partly because companies often lack information on important indirect impact elements, as well as specific details about the actual production which mostly is based on manual data-collection. To overcome these two challenges, the chapter presents a vision for a double digital shadow which integrates the production and the sustainability dimensions into one. One element of the digital shadow focuses on the production, applying concepts from Industry 4.0/Smart production, to obtain data about the actual state of the production. A second element focuses on sustainability aspects of the production using novel semi-automated, but often highly aggregated, environmental sustainability data models (e.g., EXIOBASE). In the chapter, the background and state-of-art is expounded, the double digital shadow presented, and important work on, and practical steps to, the integration of production and sustainability is outlined. (https://link.springer.com/chapter/10.1007/978-3-031-15428-7_23)

SMEs and the Sustainability Challenge: Enabling smart decision making

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Abstract In this chapter, we introduce the challenges SMEs are facing when working with sustainability, and present a vision for a digital double shadow, which extends the digital twin into the sustainability realm, building the ground for operational sustainable smart production.

Keyword: LCA, circular economy, data driven production, digital twin, smart production, i5.0

1 Introduction

It is widely acknowledged that it is challenging for SMEs to work with sustainability, and that the current radical change towards a circular economy increases this challenge. In this regard, we divide SMEs into two groups facing two different challenges. Firstly, enterprises that aims for market niches based on 'green business models', and secondly 'normal' companies that produces goods to the market and who inceasingly are being met by requirements for documentation of sustainability related KPIs, as well of improvements in sustainability performance (Das, Konietzko, and Bocken 2022). These two groups have the problem in common that the assessment of sustainability requires expertise rarely possessed by SMEs, which clearly reflects that sustainability is not the core business. Vice-versa, sustainability is mostly regarded an opportunity in the first group and an additional task in the second group. The tools applied to assess sustainability are based on a wide variety of methodologies, and the EU Commission has counted close to 500 green claim approaches, where-of about the half are used in the EU. The most serious of these approaches are based on life cycle assessment, but may still be based on different methodological assumptions that eventually lead to greenwashing-like situations, e.g., by claiming improved sustainability performance by utilizing low-carbon-intensive but supply- constrained materials, or by defining biased system boundaries. The chapter discuss this, using experiences from working with Danish and European enterprises, and recommends a uniform approach that can improve the decision support framework for improved industrial sustainability performance seen from a global perspective.

A second challenge is the reconciliation of production and sustainability. Sustainability is often assessed in the design phase (e.g through a Life Cycle Assessment). However, current sustainability assessment systems and approaches tend to be an 'add-on' to the management decision system, and provide only incomplete and overall global sustainability evaluation because they lack important indirect impact elements, especially related to land use, as well as specific details about the actual production and production inputs often mainly based on manual data-collection.

The last part of the chapter presents an overall approach for how to integrate the two dimensions (the production and the sustainability dimension) into one. Here we will apply concepts from Industry 4.0/Smart production, which is characterized by the application of data driven approaches. This opens up for new possibilities to overcome a number of the challenges presented above. As part of the research, we have outlined the structure of a generic digital twin which integrates both dimensions. In the paper, the background for this work and state-of-art is expounded, the generic digital twin presented, and important work on, and practical steps to, the integration of production and sustainability is outlined.

2. The Sustainability Challenge

How companies work with the sustainability challenge has been investigated. Das, Konietzko, and Bocken (2022) examined 68 predominantly European companies to identify how they worked with environmental impacts in relation to circular business models. They found that the most common approach to measure performance of new models was rules of thumb, followed by life cycle assessment (LCA) or LCA-based tools followed by a spread of different approaches ranging from carbon foot printing, carbon calculators and mass flow analysis to various less meaningful approaches (ibid p280). Furthermore, the barriers are reported to be lack of data, uncertainty of ex-ante assessments of product-production, time and money resources etc. These findings imply that the assessments are done with a wide range of different modelling assumptions and henceforth challenges with respect to the level of comparability. On the one hand the methodological differences between LCA and carbon footprints is just a question of reported impact categories (B. P. P. Weidema et al. 2008), and on the other hand different methods, even though commonly being LCAs and referring to the ISO standard, may give quite different answers (Bo Pedersen Weidema et al. 2020; Bo P. Weidema 2019).

It seems that companies, and particular SMEs, often has limited understanding of the use phase of the products they produce (see e.g. Harris, Martin, and Diener 2021; Das, Konietzko, and Bocken 2022), which also is the general observation of the authors. Furthermore, even though industrial symbiosis continues to grow in potential, there continues to be a need for further improving the understanding of how best to assess and address minimization of environmental impacts (Harris, Martin, and Diener 2021).

On top of these challenges, there is a profound need for transparency of the data used in assessment of performance, and this need will increase dramatically when methods applied becomes more detailed and closer to reality. The current state of the art does not accommodate this, but promising approaches are under development (Hansen et al. 2020), and these are consistent with the approach recommended in this chapter.

Below in we have outlined the different core sites where key decisions influencing sustainability performance (see figure 1). To the left we have activities that especially in the case of SMEs most often will take place outside the company, i.e. design of fundamental or novel technologies that lays the foundation of the product- and or production technology. The next four sites include from design of product and production, the ongoing operation on the shop-floor to management strategic decision. This is followed by the last 'site', which involves a multitude of stakeholders including the suppliers, distributers supply-chain and downstream users.

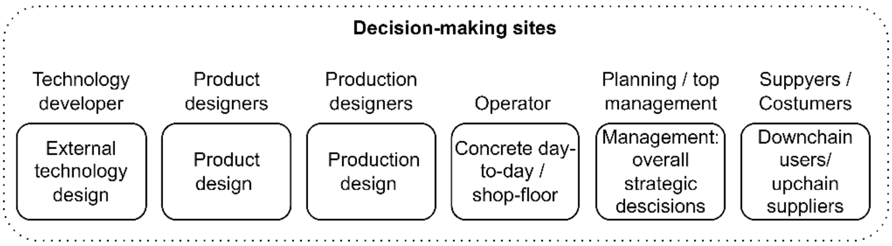

Figure 1. Instances and sites of decision-making relevant for sustainability-performance related to the production ecosystem (production, supply chains and downstream users). The relationship between production related decision-sites and the lifecycle impacts is described afterwards. This figure is the upper component of the full system model for integrating sustainability into smart production, which we develop later in the chapter (figure 4).

At these sites, different questions related to sustainability and environmental performance will arise. Today, the predominantly request for performance evaluations are to be found when developing new/novel technology designs and in relation to user requirements. When developing novel technology with EU funding i.e. in the Horizon programs where there is a strong SME-focus, these questions are default, and more important. When seeking investments, finding employees, selling products, the external stakeholders (costumers and downstream users, future employees, investors) are increasingly requiring life cycle performance documentation, often combined with the requirements in the Science Based Targets Initiative (SBTi), commitment to the Carbon Disclosure Project (CDP), use of environmental product declaration schemes (EPD). Often SMEs are not prepared for working in these dimensions, which is why the Danish Industry Association has initiated ambitious programs preparing SME companies to the climate competition they increasingly find themselves in[1].

The experience is – as Kermit noted it: It is not easy being green! Many companies are uncertain how to begin exploring and documenting environmental performance. Often the capacity of working with sustainability has positive implications on digital competencies as well as the cost level – the cheapest material and the cheapest electricity is the ones you do not use! As an example, the Danish company Danfoss supplying mechanical and electronic solutions to heating, RE-systems and more, are currently – in 2022 – running 200 projects improving company environmental performance with an average payback time of 2.8 years[2]!

To make this simpler, let us think of a company producing a simple range of products i.e., pans. The company uses aluminum and electricity as the primary production inputs, and the questions such a company are likely to ask includes the following:

Where do the emissions related to our products come from? Which materials should we chose? Where should it be sourced from? How will my product perform in different end-use contexts? How will my products perform in the end-of-life phase (EoL)? Should we prioritize recycled materials? Should we do what we can to increase recyclability and repairability of the products? Which requirements should we give to our suppliers? And most importantly: where do we best contribute most to the global decrease of harmful emissions and impacts?

Recycled materials are important but will often not significantly improve product sustainability performance: for example, if you use recycled aluminum, you will use a resource that is 'constrained', which means that an increased demand will be matched by increased production where this is not constrained (which happens to be Chinese aluminum production[3]. Still, it is a possibility to save materials from being lost, but this will typically either only be something that will be a transient situation or what economists would term a 'market failure': the normal state with a well-functioning circular economy will not be that materials are 'saved' but rather that they become integrate parts of the economy alongside virgin materials.

[1] 'Climate ready SME' assisting SME companies creating organizational carbon footprints, and to understand the climate impacts of company decisions: https://www.danskindustri.dk/klimaklarSMV/, with participation from DI, Axcelfuture, Global Compact Network Denmark, Aalborg University and Viegand Maagøe. This project was concluded in 2022 and has been extended with 'Climate Ready production company', running until 2026, and including all 12.500 Danish production industries.

[2] Example presented by the Danfoss-CEO at the closing conference of the 'Climate ready SME' project (https://www.danskindustri.dk/klimaklarSMV/).

[3] The absolute dominance on global aluminum production resides with China both in terms of absolute increase in production capacity and in relative proportion of total production capacity, which mean that increased demand for aluminum is answered by production increase in China (https://international-aluminium.org/statistics/primary-aluminium-production/).

Alternatively, if the material is overpriced compared to 'virgin' alternatives, then this may reflect that the material in fact is ‘saved’ from being lost. The recycled materials challenge can also be understood in the context of circular economy: in a fully developed circular economy there is no important difference between recycled and virgin materials, and using recycled materials is just a normal situation where market mechanisms secure an optimal use of the materials (recycled aluminum is typically suitable for casting but not for extrusion). Basically, the impact in this situation is that the company rather than focusing on reducing its impact by utilizing recycled aluminum, it should focus its efforts on reducing the need for aluminum, either by reducing aluminum inputs or by extending lifetime, repairability etc.

This example shows how the intuitive answers to central questions not always are the relevant answer,if the aim is reducing the use of resources and impacting on the environment. Getting this right, needs both the relevant data and the right modelling principles. In the following, we elaborate how these questions can be dealt with.

3 Measuring sustainability – what meets the SME?

Sustainability and environment are rarely the core business of a company. We will therefore dwell a bit on how the performance are being measured, and what approaches meets the SME wanting to engage with the transition to sustainable production. Our core message is that the company needs to invest the resources necessary to understand how the production and the products are connected to emissions, not only from the activities onsite, heat and electricity purchased, but also from materials and services purchased, and from downstream use and end of life. This is essentially what are being assessed in a life cycle assessment, where the aim is to assess inputs and outputs from the full lifecycle of the product. As illustrated in figure 2, the main phases start with extraction to production, through the use-phase to the end-of-life of the products produced, and the implication of the circular economy is in the figure added as black arrows indicating reuse and recycling.

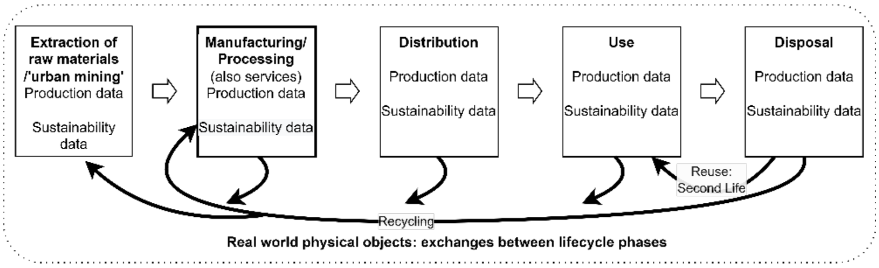

Figure 2. Main phases which any activity ‘activates’. Often, analogues to this figure is depicted as a circle, and the black arrows is identical to the ‘closing the loop’ arrows in illustrations of the circular economy. Without the black arrows the figure represents the linear economy, and with

the increasing strength of the black arrows, the figure represents the circular economy. This figure is the lower component of the full system model for integrating sustainability into smart production, which we develop later in the chapter (figure 4).

We acknowledge that seen from a company, this is somehow abstract, as the Manufacturing box represents all manufacturing activities in the global economy. A more concrete representation of a production will involve many types of manufacturing including purchase of heat and electricity, materials, semi-manufacture and services. Any production will therefore draw on activities coming from all five activities, including inputs from other manufacturing companies.

The unit of measurement at company level will be either the full company activities i.e., per year, or per specific product or service also in a measurable unit (in LCA-terminology this is called the functional unit or FU and all activities, inputs, co-products, and emissions are related to the FU).

A number of approaches addressing this is available. When looking to the assessment of company specific activities, the Science Based Target initiative (SBTi) initiated by the World Resource Institute together with Climate Disclosure Project (CDP), WWF and the UN Global Compact in 2018, is probably today some of the most influential initiatives. The initiatives target best-practices in emissions, methods and guidance to companies to set science-based targets aiming for the 1.5°C UN-target. SBTi uses the Greenhouse Gas Protocol (GHG-P) as basis for calculations, but several approaches can be added to the SBTi and the GHG-P.

The most important systems in the EU are the European Product and Organization Environmental Footprint (PEF/OEF), and the International Environmental Product Declaration (EPD), that further require definition of specific product category rules and Product Environmental Footprint Category Rules (PCR and PEFCR respectively) which are guidelines on how to apply life cycle assessment on specific product-groups or activity types. These are rules for consistently producing environmental footprint analysis of specific products within a specific product category. These systems have been established to resolve challenges in the overall ISO framework, but has resulted in specific new challenges, as e.g. the PEF system may not conform with the internationally agreed on principles for LCA (ISO 14040/44), and even partly contradicting these (Bach et al. 2018). Furthermore, the EPD system has resulted in a proliferation of PCRs which are defined in a bottom-up consensus process, which, due to the negotiation processes involving stakeholders with different power and vested interests, has led to inconsistency and incomparability between PCRs (Wilfart et al. 2021). Furthermore, a high number of national and NGO-driven methods, including BPX 30-323 for France, and specific GHG-oriented methods as the before mentioned GHG-protocol and the British PAS 2050 exists, and these standalone guidelines has various degrees of comparability with the previous ones.

A central issue related to most of these approaches, is that they are based on normative modelling, also called attributional modelling, which is less relevant when performing decision support related to changing the supply to the market as consequence of changes in production. Instead, we recommend a consequential approach applied, which especially becomes important when the economy increasingly becomes circular (EC-JRC 2010, 70; Bo P. Weidema et al. 2018; Schrijvers, Loubet, and Weidema 2021; Geyer, Jambeck, and Law 2017; Zink, Geyer, and Startz 2016). The goal is to support companies with the ability to act in trade-off situations and avoiding suboptimization and seeking solutions that supports *system-wide sustainability* and which *avoids* counterproductive blame-games and *competition for constrained resources.* Examples of the latter (to avoid) are purchase of green electricity where the purchase is not accompanied with explicit additionality, or where the greenness of the production is pursued by using recycled aluminum without securing additional recycling of aluminum.

However, the SME should not get frustrated by the method discussions, because the issues under discussion are not related to the accounting of activities but rather to the methods for how to account for the related emissions(Bo Pedersen Weidema et al. 2019). This means that the company basically should work with collecting data with a robust strategy, which is collecting relevant and traceable raw data on exchanges and emission (Hansen et al. 2020; Ghose et al. 2021), instead of collecting calculated emission-data, e.g. EPD based carbon footprints. Basically, SME companies need to put efforts into building inventory of data needed for environmental assessment in a method neutral structure, which then can be recalculated into method-specific lifecycle-inventories (LCIs) and according to the relevant standards (International Organization for Standardization [ISO] 2006a; 2006b; 2.-0 LCA consultants 2022).

Important obstacles for SMEs pursuing the sustainability agenda can be summarized to 1) sustainability data is often translated into assessments that depend highly on external experts, 2) Assessments are often detached from everyday practice in the company, as the transformation from physical data to impact assessment, e.g. carbon footprint, is strongly method depended, 3) decision support is often experienced as less relevant at many decision sites in- and outside the company, and does therefore not significantly influence decision making.

In other words, what is needed is that the company take back the data and enable partly improved data management enabling lower cost for carrying out assessments, partly improved accessibility to navigate the sustainability dimension in a production reality that will change with an increasing pace.

In 'old days', when focus was on mass production and mass customization, the time-lag and relatively high costs related to doing a sustainability assessment leading to a sustainability-optimized design which then should be put into production could be acceptable. But two different conditions have changed. Firstly, the urgency of improving environmental performance of products, including their production and use, has increased dramatically with the increasing urgency of the climate change problem (IPCC 2022), and recognition of the sustainability challenge represented by the UN sustainable development goals (United Nations and The General Assembly 2015; Scheyvens, Banks, and Hughes 2016)

Secondly, smart production, Industry 4.0 or the next generation Industry 5.0, are likely to imply that the boundaries between design, production-design and production will become more blurred. IoT will create the basis for this, partly by internally connecting the information flows in production, partly by connecting information from both supply chain, use chain and end of life processing.

This is a *projected* future, which is not yet here, or at least not yet relevant in full scale for most small and medium sized enterprises. The challenge, therefore, is how to prepare for this situation (assuming it will arise), and not least how to harness the information flows to best accommodate, not only improved productivity, but also improved environmental performance, and in this way contribute to how smart production will be enacted.

4 Vision for a digital double shadow

The challenges in sustainable and smart production can be conceptualized largely in the same terms. Smart production is about integration both with respect to production parameters as well as sustainability parameters, and digital twins and shadows hold a great potential for enabling and operationalizing this integration. In relation to production, Kritzinger et al. (2018) has coined this as the difference between 1*) digital models* being digital representations of reality but with manual connections between reality and model, 2) *digital shadows* where the model is feed with real-life data (automatic data flow), and finally 3) *digital twins*, where the advanced models with automatic data input, automatically feed data back to the production-system. In other words, to have a digital twin it is not enough to have a digital model, it is required to have two-way interaction between production-reality and the model, and importantly, that the model can change with changing production reality. This situation is fully mirrored when it comes to sustainability modelling using LCA (which today almost solely is environmental impact modelling): Today, data flows in sustainability modelling and LCA are mostly manual! A typical system representation in LCA – a life cycle model, which in the professional jargon is the Life Cycle Inventory (LCI) is a digital model of the environmental performance of the production-reality. This is depicted in figure 3, upper part, where the digital model is connected with the production reality by manual data flows, i.e., experts interviewing production controllers and collecting and selecting relevant data inputs.

Smart production and Industry 4.0 are often being articulated as an enabler for sustainable development in enterprises (see i.e. Carvajal et al. 2019; Dagerman, Lukas, and Wahlster 2015; Baumann 2017; Niehoff and Beier 2018; Pfeiffer 2017; Kagermann, Wahlster, and Helbig 2013). However, in general, the connection between smart production and sustainability has until this point seemed to be strongest in the toasts and speeches, which also is a central improvement point in what has been coined Industry 5.0 (European Commission et al. 2021). In line with this, we here present a conceptual model for how the similarities between the techno economic ‘production’ digital twin, and the emerging approaches for lifecycle assessment leaves a good space for creating linkages, as life cycle modelling can be viewed as just another digital model of the production reality. In the terminology of Kritzinger et al (2018), current LCA digital representations are models, i.e. the top right corner of figure 3, but as with the digital production models, or techno-economic models as we call them here, the precision and relevance of the models is 'just' a question of how fine-meshed data collection we can make for foreground system modelling.

The challenges with the current 'manual' LCA-models outlined in the previous section is that the prevalent 'digital-LCA-models' conflates the representation of impacts with the input data, as the entities reported typically is the 'carbon footprint' per unit of input, instead of the physical flows per unit of input which is needed for proper analysis (WRI and WBCSD 2013, 22) and this leads to a modelling which is not robust with respect to modelling assumptions. Stepping further down in the figure, the possibility for separating modelling assumptions from data collection increases, and henceforth does the robustness of the modelling, as different modelling assumptions answering different questions can be calculated in different layers.

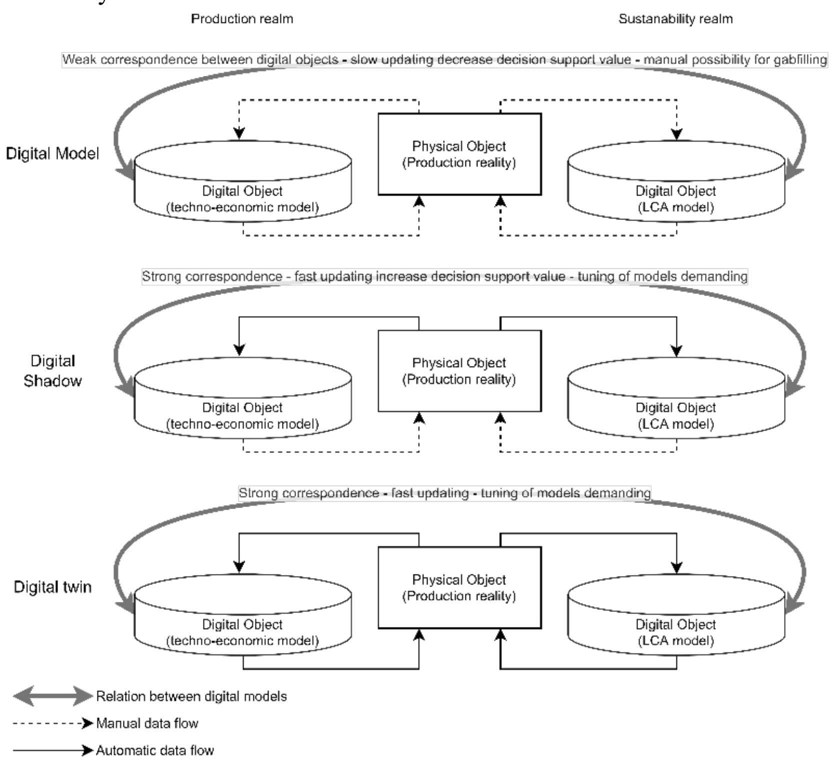

Figure 3. Topology for digital models of the production reality, conceptualized as twin-digital representations of the production reality. To the left is the representation as Kritzinger et al (2018) sketch it focusing on the manufacturing reality, and to the right the representation focusing on sustainability aspects of the production reality. The twin-approach is pragmatic and based

on actual modelling practice, but the twin structure may be merged into a single digital representation.

The challenge we face is therefore a combination of one the one hand a need to take the right decisions, and on the other hand imperfect knowledge. Following the Kritzinger terminology the data representation can be done using digital model, digital shadows, or digital twins. We recommend aiming for digital shadows, not only because it is less ambitious and therefore more realistic, but also because we believe it to be a more relevant solution. The main challenge, in our eyes, is not to automate decision making but to gain relevant decision-support, enabling making the right decisions. One might say that sustainability is too important to leave with algorithms – on the contrary – sustainability requires consciousness, and it is therefore digital shadows that efficiently collects the relevant data and provides an open platform for interpretation, which is needed.

With respect to the digital sustainability representation of the production reality the focus of the company needs to be at two different levels. The first is to collect data which is relevant (Ghose et al. 2021), the second is to understand the impact potentials of the company, its production related decisions, and its products. As we have pointed out above, the data collection must be separate from the calculations of impacts, as these calculations will differ depending on the analytical questions asked, and even more importantly, the management of the company comes in control of the data that are used for the sustainability assessment in a form which is robust when encountering changing norms for how to do the assessments, and where the decisionmakers becomes educated in how decisions influence system sustainability performance. This may be improved understanding of impacts related to biomass (e.g. biodiversity, indirect landuse change), changes in how waste-based inputs should be counted, due to changing systems for recycling, or how constrained resource inputs should be modelled.

The latter is important, as this includes system aspects that lies outside of the normal production supply chain focus, as the aluminum example above show.

This way of organizing the sustainability related data with a focus on physical data describing the systems resembles the way ‘normal’ production models function, so by incorporating the sustainability modelling framework into the framework already known by production people we ease sustainability becoming a decision parameter at par with techno-economic decision parameters: sustainability KPI’s are best be communicated in a way that production people are trained in understanding.

The sustainable digital double shadow is our effort in turning this generally shared vision of sustainability into a concrete action-oriented and operational reality. The model conceptualizes how to bring sustainability into the shop floor, the boardroom, the designer desk, and the consumer’s mind. The double digital twin is a tool to connect tools for production monitoring and optimization of both economic and sustainable nature. Ultimately, all of this should become one digital twin, but our proposal and recommendation are to focus on creating an extra twin for enhancing sustainability to the digital twin, and we call it the sustainability twin (see figure 4).

To the left hand we have the traditional inputs to models, shadows and twins, basically leading to decision support. To the right we have the sustainability twin, which in principle are feed with the same data type of data as the production twin. The real-world data feed is illustrated at the bottom, and the types of flows that typically get most attention today is those related to manufacturing (onsite and purchased) and transportation.

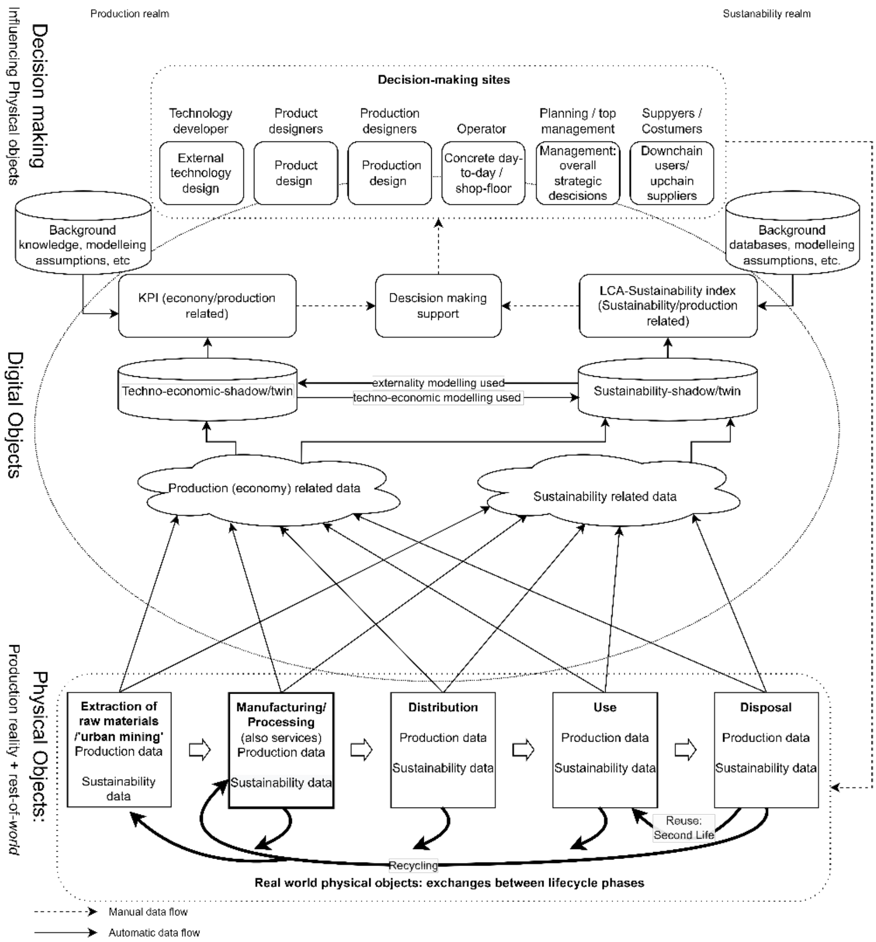

Figure 4: The production/sustainable digital shadow. Dataflows marked are with arrows. When dataflows are manual, we speak of digital models instead of digital twins. When feedback from models we talk about digital shadows.

Outermost to the left and to the right, background data for both twins are market databases, background data, modelling assumptions etc. necessary to interpret the collected data. To the sustainability side this type of data is beginning to be available in semi-automated but highly aggregated form, i.e., with the EXIOBASE data that are open access (Tukker et al. 2014; Stadler et al. 2018; NTNU et al. 2015; Merciai and Schmidt 2018), and which has informed the projects run by the Danish Industry federation mentioned above. One of the advantages of the data is that impacts can linked both to physical entities, as well as to monetary entities, and that specific data are available for 43 countries and regions covering the global economy. EXIOBASE reflects real life global economy data, but in the current form these data are still expressions of manual data flows. However, it is in the pipeline to create versions of the data which are continuously updated (AAU 2021), enabling increasingly accurate performance evaluations. Furthermore, this type of database enables the creation of qualified estimates of impacts based on economic data, as well as on physical data.

The collection of data at company level will in a foreseeable future be interlinked as distributed ledger technology will enable automated transfer of data without hampering production secrets. The current focus is on registering i.e., plastic qualities and traceability (Brøns et al. 2021; Licht et al. 2019), but these approaches will become normal for all exchanges in economy, as the sustainability challenge calls for three types of information following all products; price-, quality- and sustainability-data. This process is already going: Digital product passports is an important aspect of the European Sustainable Products Initiative (SPI) under the European Green Deal (European Commission 2022b; 2022a). This mean that the need for pursuing capacity building within sustainability data management will increase. In the proposal, the digital product passport will electronically share product-related information amongst supply chain businesses, authorities, and consumers.

An import aspect of these new regulations is that the company building capacity to control own data, and to request relevant data from the supply chain, will be surrounded by companies forced into similar considerations, which mean the demand for relevant data will be eased. Even more importantly, the companies building this capacity before the regulatory pressure arises will have a competitive advantage, as the data approach we here suggest will be robust regarding specific requirements that may defined either by specific customers or in future regulations such as the Sustainable Product Initiative.

Conclusion

For the SME a key question will be to work with sustainable system-understanding, and for this purpose aiming at building relatively simple models supporting the increasing pressure for taking relevant sustainability decisions. It is important that these models focus on physical exchanges, which is the prerequisite for making relevant impact modelling answering to the specific questions that arise in the different sites for decision making. The most important question is how changes in production influences impacts in a global context which includes induced production, but other perspectives may also be needed due to customer requirements, i.e., impact modelling in accordance with some of the specific method frameworks mentioned above. The important point here is, that the company must focus on collecting data in a form which is method neutral, and then – together with domain experts – develop an understanding and consciousness of how the company activities are connected to emissions and the sustainability challenge in general. When this is in place, then the next steps can be increased manual and automatic data collection from production and suppliers, where use of distributed ledger technology, digital product passports and like platforms can come to play an important role.

Using the vision for the sustainable shadow connecting data from reality, the company should start with simple data-collection and -deployment, aiming at becoming interlinking these data in models to support the company in making decisions furthering sustainability and thereby competitiveness.

Working along these tracks will have transformative power for the understanding of the relation production and sustainability and will be a key competitive parameter.

As future work we plan to make a prototype implementation of the proposed double digital shadow in the AAU Smart lab (Madsen and Møller 2017), which will be important for the dissemination and mutual learning processes across the sustainability and production domains, as well as across production practice and production research.

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